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Delivery and viability of landfill gas CDM projects in Africa—A South African experience

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ABSTRACT

The eThekwini Municipality (Durban, South Africa) landfill gas Clean Development Mechanism (CDM) project was the first to be registered and verified in Africa. The idea for the project was developed in 2002, yet it was not until the end of 2006 that the smaller Component One (1 MW) was registered, while the larger Component Two (9 MW) followed only in March 2009. Valuable lessons were learnt from Component One, and these were applied to Component Two. The paper describes the Durban CDM process, the lessons learnt, and assesses the viability of landfill gas to electricity CDM projects in Africa. It concludes that small to medium sized landfill gas to electricity CDM projects are not viable in Africa unless there is a renewable energy feed-in-tariff, or unless the gas is simply flared rather than being utilised for power generation.

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Table 1
Summary of the three municipal sanitary landfills that house landfill gas CDM projects in Durban.

	Bisasar Road	Mariannhill	La Mercy
Size	44 ha	33 ha	7.2 ha
Firstly established	1980	1997	1980
Location	Urban	Peri-urban	Rural
Configuration	Deep valley landfill with lined cells on an old attenuation/unlined waste body	Valley landfill operated in 5 lined cells	Valley attenuation landfill
Waste type	General municipal solid waste, garden refuse and construction and demolition waste	General municipal solid waste, garden refuse and construction and demolition waste	General municipal solid waste, garden refuse and construction and demolition waste
Capacity	21 million m^3	5 million m^3	1.1 million m^3
Average depth	40 m	18 m	15–20 m
Deposition rate (1 Mton/year)	3000 tons/day	550–700 tons/day	300 tons/day
Expected closure time	2013	2022	Closed in 2006
Biogas extraction system	Yes	Yes	No
Leachate treatment	None	Sequencing Batch Reactor	None
Other facilities	Weighbridge	Weighbridge Material Recovery Facility (MRF) Conservancy area	Weighbridge

1. Introduction

Durban Solid Waste (DSW) manages waste within the eThekwini Municipality (Durban, South Africa). In 2002, DSW initiated, in collaboration with the University of kwaZulu-Natal, the first African landfill gas to electricity CDM project in three of the main sanitary landfills in the city of Durban (named: Bisasar Road, Mariannhill and La Mercy) [11].

The project was to be financially supported by the World Bank's Prototype Carbon Fund (PCF). The PCF is one of the many carbon financing mechanisms operated by the World Bank, established in July 1999 (early-on in the evolution of the international carbon market) *inter alia* with the intention of assisting with market initiation by promoting investment in CDM and Joint Implementation (JI) projects that could be registered under the Kyoto Protocol (www.carbonfinance.org). The PCF is a public–private partnership consisting of six governments (Canada, Finland, Norway, Sweden, The Netherlands, Japan) and 17 private sector companies (13 energy companies, two financial institutions and two trade companies), with a total budget of US$ 180 million. In the operation of the PCF the World Bank was mandated to identify appropriate projects for investment, and to secure CERs, which are then distributed, to the participants in the PCF according to their percentage of investment in the Fund. As an early carbon financing mechanism the PCF's portfolio has been closed for some time, while the World Bank has continued as a player in the international carbon market, including through the development of a series of other carbon investment funds. However, in 2002, the discussions between the World Bank and eThekwini, under the auspices of the PCF, were novel in the context of international carbon finance. Following the origination of the idea for a landfill gas CDM project in 2002, a financial model to assess the viability of the project was prepared in 2003. This indicated a 4-year pay back period [11].

Whilst viability is fundamental to the delivery of such projects, all the three major strands of sustainability were considered by the eThekwini Municipality in the implementation of the Durban project: improving the *environment* locally and globally through the management of waste and landfill gas, providing *social* development through employment and skills-transfer and *economic* return.

This paper describes the history and process of the eThekwini landfill gas CDM project since 2002, and assesses its viability at the start of 2010. The objective of the paper is to provide the reader with details of the lessons learnt, and to comment upon the viability of similar CDM landfill gas projects in Africa.

2. Project rationale and initiation

2.1. Waste management in Durban

Durban is the largest city of the eThekwini Municipality with around 3.5 million inhabitants served by one regional and three municipal sanitary landfills that house the CDM projects: the Bisasar Road landfill situated 7 km from the Durban CBD (Central Business District), the Mariannhill landfill located in the western area of the Durban unicity around 20 km to the west of Durban in the Metro area formerly called the Inner West City Council (IWCC), and the La Mercy landfill located 35 km north of Durban in the metro area formerly called North Local Council (NLC). The main characteristics of these three municipal sites are summarised in Table 1.

eThekwini Municipality has been combusting landfill gas at Bisasar Road landfill since 1996 when a Hofstetter extraction flare was installed to control landfill gas migration around site facilities. Landfill gas has also been combusted at the Mariannhill landfill since 2001 when a Realmside plant was installed to extract and flare gas from cells 1 and 2. Wells on these systems were connected to the new CDM projects to form the baseline flow, although the old gas extraction plant and equipment were removed and replaced.

2.2. CDM project assessment

A Certified Emissions Reduction (CER) evaluation report was prepared in May 2003 with the aim to predict the CERs in tons of

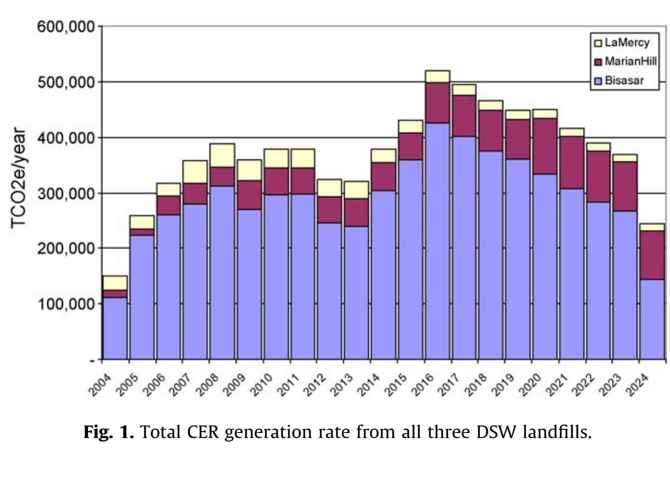


Fig. 1. Total CER generation rate from all three DSW landfills.

Table 2
CDM scenario assessment, 2003 financial model.

Item	Scenarios: years of CDM project eligibility			
	14 (7 + 7)	10	7	0
Project NPV—South African Rand	R9,703,794	R2,026,935	R11,107,570	R50,544,945
Project NPV—US Dollars	$1,386,256	$289,563	$1,586.796	$7,220,706
Project internal rate of return	14.70%	11.20%	0.86%	Negative
Tons of emission reductions (CERs)	3,800,000	2,866,196	1,673,165	0

Scenario 1: 7-year CDM crediting period from 2005 with one renewal of the crediting period in 2012.
Scenario 2: 10-year CDM crediting period with no renewal.
Scenario 3: 7-year CDM crediting period, delayed project with no renewal.
Scenario 4: No CDM and no CERs.

carbon dioxide equivalent (tCO_2e) for 21 years. CERs are a measure of carbon credits associated with CDM projects, and each CER represents 1 tCO_2e mitigated. Profiles of expected CER generation over the life of the three sites are shown in Fig. 1. Gas calculations were made using a first order decay model prepared by Oxford University (UK), and subsequently compared with the first version of the GasSim model [3]. The GasSim model includes a single-phase first order equation to emulate the "LandGEM" model developed by the US-EPA. Ultimately, the GasSim model was preferred to other models, as it yields 4% lower values than LandGEM and meets the requirement that a conservative approach is adopted in technical assumptions underpinning CDM projects.

Negotiations were held with the World Bank and a Memorandum of Understanding was agreed in February 2003. In June 2006, an Emissions Reductions Purchase Agreement (ERPA) was signed in Cologne (Germany), with the International Bank for Reconstruction and Development as the trustee for the PCF, in respect of the GHG emissions reductions potentially to be generated at all three sites. From the sustainability perspective, it is significant to note that, among the conditions included in the ERPA (which suspended certain elements of its operation until their fulfilment), was the requirement for eThekwini to apply for, and be granted, the necessary environmental authorisations required, according to South African law, to undertake the proposed project activity. An environmental authorisation to undertake a particular activity may be granted after an Environmental Impact Assessment (EIA) has been conducted in respect of the activity, and must be provided, in writing, by way of a positive Record of Decision (RoD) (*PCF Operational Cycle*, www.prototypecarbonfund.org).

By virtue of its agreement with the World Bank, eThekwini had agreed to develop the first landfill gas to electricity project in Africa, which was anticipated to deliver CER credits for sale to the PCF. The agreement with the PCF involved the sale of a total of 3.8 million CERs for a total value of $15.0 million (fifteen million US Dollars—approximately one hundred million SA Rands) over 14 years. This comprised 700,000 CERs on "Component One" for the Mariannhill and La Mercy sites, and 3.1 CERs on "Component Two" for the Bisasar Road site.

Outline designs of landfill gas management systems for the three sites were prepared, and gas generation and CER calculations made, together with a financial model to assess the viability of the project. The rate of return from four CDM scenarios was assessed as summarised in Table 2.

The project was calculated to have a positive rate of return for a single, 7-year CDM crediting period, with a return of $4.2 m for a 14-year (7 + 7 years, i.e., a 7-year crediting period with one renewal) scheme combusting 3.8 MtCERs as summarised in Table 3. It was decided to proceed with the Project Design Document (PDD) on a 7-year CDM crediting period with options for renewals, rather than a single 10-year crediting period with no renewals. The 2004 financial model concluded that the project was not viable to eThekwini Municipality without CERs. This demonstrated "Additionality", although the issue did not have a high profile with the UNFCCC in 2004. The profile of "Additionality" increased during the registration process, and had to be revisited and demonstrated in detail for the registration of Component Two.

Table 3
CDM base case, 2003 financial model.

Base case crediting scenario (7 years with single 7 year renewal)	Sum
Total capital investment (in real terms based on 2004 SA Rand)	R61,670,255
Total operating expenditures (real rand-inflation adjusted)	R37,754,876
Total accrued income to maintenance account (real rand-inflation adjusted)	R1,494,433
Total accrued income to re-engineering account (real rand-inflation adjusted)	R1,494,434
Total net income to retained project earnings (real rand-inflation adjusted)	R29,601,797

A PDD for a single project for the three landfill sites for 7 years, with the options for two renewals up to 21 years was initially prepared. Assumptions for the model included: South African Rand 7.00 = United States $1.00 (currency sensitivity was modelled), $3.75 CER; 700 m^3/h per 1 MW, 91% engine efficiency. Landfill gas generation was calculated using GasSim [3] with a maximum recovery of 80% depending on the timing of installation of the wells. The financial model had CERs being generated from 2005 and calculated a payback period for the project within 4 years (i.e., by the end of 2009). Payback period in the financial model is defined as the time required for the CERs to pay off the initial investment. It was quickly realised that this planned programme was not practical due to:

- An unexpectedly lengthy period required to secure the necessary environmental authorisations;
- The procurement and construction of the gas extraction systems;
- The delivery time for engines (6 months from the date of order);
- Validation and registration procedures under the CDM process taking on average around 15 months for CDM projects; and
- The verification and CER issuance process taking up to a further year.

More over, uncertainties in the way quality and quantity of the gas were measured constituted a real risk against the long-term sustainability of the project.

3. Project development

3.1. Emissions Reduction Purchasing Agreements (ERPA)

The eThekwini Municipality started to negotiate an ERPA with the World Bank PCF in 2002, and a CER price of $3.75 was agreed in 2003, with an additional $0.20/CER up front payment into a Social

Benefit Fund (i.e., a total price of \$3.95/CER) for a volume of 3,800,000 CERs. eThekwini was free to offer for sale on the international carbon market any quantity of CERs generated in addition to this volume. The up front payment to the Social Benefit Fund was to be made upon registration of Component Two as a CDM project activity. This was considered a reasonable price at the time, i.e., in the early stage of carbon market development. The deal with the PCF also fairly typical for the time in that it included payment, by the Buyer, of the costs of the CDM project cycle in addition to an agreed price per CER. As abovementioned, the operation of the ERPA was conditional on the granting of the relevant environmental authorisations to the project. The environmental authorisation for Mariannhill and La Mercy was finally approved in February 2005. By December 2005, when construction of Component One was ready to commence, the CER market price had risen to over \$8/CER. With no certainty over the delivery date of Component Two due to the Record of Decisions (ROD) Appeal, and with considerably higher CER prices available, the World Bank and PCF fund agreed that eThekwini could remove Component Two from the Memorandum of Understanding (MoU). The World Bank has been most supportive to eThekwini, and agreed to this change to maximise the value of Component Two to the Municipality, whilst also agreeing to a \$3.95/tCO_{2e} CER price for Component One. The MoU was not a binding agreement until the projects had been registered.

In 2008, after the Component Two project was registered, and after a period of negotiation, eThekwini signed an ERPA with TEP (Trading Emissions Plc) until 2012. TEP has built up one of the largest and best delivered CER portfolios in the world. This was considered a good deal given the volatility in the CER market. CERs have traded at around \$11–\$15 over a number of years to 2009, and at the end of 2009 were trading up to \$16.3 (€12, the value of the European Union–Emissions Trading Scheme (EU–ETS)).

3.2. Environmental authorisations

Applications for environmental authorisations for the three sites were made early in 2004. As abovementioned, the competent authority took some considerable time before granting the environmental authorisations. Upon the granting of the environmental authorisations for each of the three sites, certain interested and affected parties launched appeals against the authorisations.

Records of Decision (ROD) authorising Component One were issued in terms of the requirements of section 22(3) of the Environment Conservation Act (Act73 of 1989) (ECA) by the DAEA only in July 2004.

An appeal was immediately lodged against the DEAE Component One ROD in August 2004. The Appeal was primarily made on the potential health effects from emissions of combusted gas from flares and engines. Subsequently, further evidence was provided that the gas management systems as designed and specified would not pose an unacceptable emissions risk, and it was ruled in February 2005 that the Component One project could go ahead subject to additional emissions monitoring.

The ROD approving Component Two was finalised in November 2004 for a design with 165 wells supplying six 1 MW engines. As for the Component One project, the ROD for Component Two was appealed primarily on the grounds of the health risk posed by the emissions from the engines. A detailed comparison study was carried out on the emissions, which would result with and without the proposed landfill gas electricity generation scheme. Four groups of substances were identified as being of potential concern:

- Combustion gases such as oxides of nitrogen, sulphur dioxide and hydrogen chloride
- Volatile organic compounds such as benzene;
- Semi-volatile organic compounds such as dioxins and furans; and
- Trace metals such as arsenic and nickel;

Emissions of substances associated with landfill gas combustion were clearly higher if the project went ahead. Conversely, emissions of substances associated with raw (un-combusted) landfill gas would be higher without the project. The study concluded that projected emissions of all released substances in presence of the project would comply with relevant air quality standards and guidelines.

The appeal was completed and a revised ROD issued in August 2006, some 21 months after the Appeal was made, resulting in a significant delay in the commissioning of Component Two. The ROD for Component Two was for 6 MW produced by six 1 MW generators, each requiring a conservative gas flow of 700 m^3/h at around 45% methane. The Jenbacher engines installed require around 600 m^3/h at around 50% methane, which means that, considering the natural fluctuations in gas production over time, will ultimately support around 8 MW.

3.3. Design and budgets

The 2005 outline design and cost estimates for the three sites were:

(a) *La Mercy*. the anticipated works comprised installation of 8 wells in the old waste body and 8 wells in the newer section, a blower and 1000 Nm^3/h flare, and a 0.5 MW generator. eThekwini was informed of the risks in providing a generator at La Mercy because the gas generation yield and quality were uncertain, since no pumping trails had never been carried out. However, DSW wished to proceed with the project with the plan to flare the gas at La Mercy and transfer the generator to Bisasar Road. The initial cost estimate for works at La Mercy was \$1.1 m.

(b) *Mariannhill*. seven new wells were required plus pipe-work to connect to the existing baseline wells. These were to supply a 1000 Nm^3/h flare, and a 0.5 MW generator. The initial cost estimate for Mariannhill was \$0.74 m When La Mercy and Mariannhill were combined into a single Component One project, the slightly increased cost estimate for extraction and flaring works was \$0.94 m (contract reference WS5607), and \$1.1 m for two 0.5 MW generators (WS5608). With the aim to cut costs, it was decided to have two distinct contracts for each Component: a gas extraction and flaring contract and an electricity generator contract.

(c) *Bisasar Road*. The Bisasar Road landfill gas management system was designed on the basis of 115 vertical wells (each extracting gas at 35 m^3/h) and 48 upslope risers (each extracting gas at 18 m^3/h), giving a total flow of 4889 m^3/h. Twin 450 mm OD (outside diameter) pipes were designed to transport gas to the extraction compound and it was calculated that this gas flow (at around 50% CH_4) would support 7.5 MW of electricity generation. This translated into an initial extraction and flaring contract of 50 new wells, with twin pipe-work up to 450 mm OD; two 2500 Nm^3/h blowers; 2000 Nm^3/h flare; and a compound for up to 8 MW with 3 MW installed in the first phase. The cost estimate for the engineering works for the gas extraction and flaring system was \$2.6 m (WS5627), and the cost estimate for the mechanical and electrical engineering works and generators was \$1.8 m (WS5628).

The specification for the design of the pipe-work was a maximum velocity of 7 m/s at the design flow, and minimum

gradients of 5% where the grade is counter to the gas flow and 2% where it is in the same direction as the gas flow. This pipe-work design has been sound through 3 years of operation with no issues of high suction pressure or condensate blockages in any pipe.

4. Clean Development Mechanism (CDM)

4.1. CDM process

The United Nations Conference on Environment and Development (UNCED) Earth Summit took place from 3 to 14 June 1992 in Rio de Janeiro, Brazil [13], the outcome of which was a series of treaties (agreements):

- Agenda 21; Rio Declaration on Environment and Development;
- United Nations Convention to Combat Desertification (UNCCD) (i.e., deforestation);
- United Nations Framework Convention on Climate Change (UNFCCC); and
- United Nations Convention on Biological Diversity (CBD).

The UNFCCC is a multilateral convention aimed at stabilising greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. The Rio Earth Summit set no mandatory limits on greenhouse gas (GHG) emissions for individual nations and contained no enforcement provisions. Rather, the Rio treaties are implemented by 'Conferences of the Parties' (COP) which include provisions for updates (called "protocols") that would set mandatory emission limits. The Kyoto Protocol to the United Nations Framework Convention on Climate Change was adopted by COP-3, in December 1997 in Kyoto, Japan, after intensive negotiations [14]. Some industrialized nations, including central European economies in transition (all defined as Annex 1

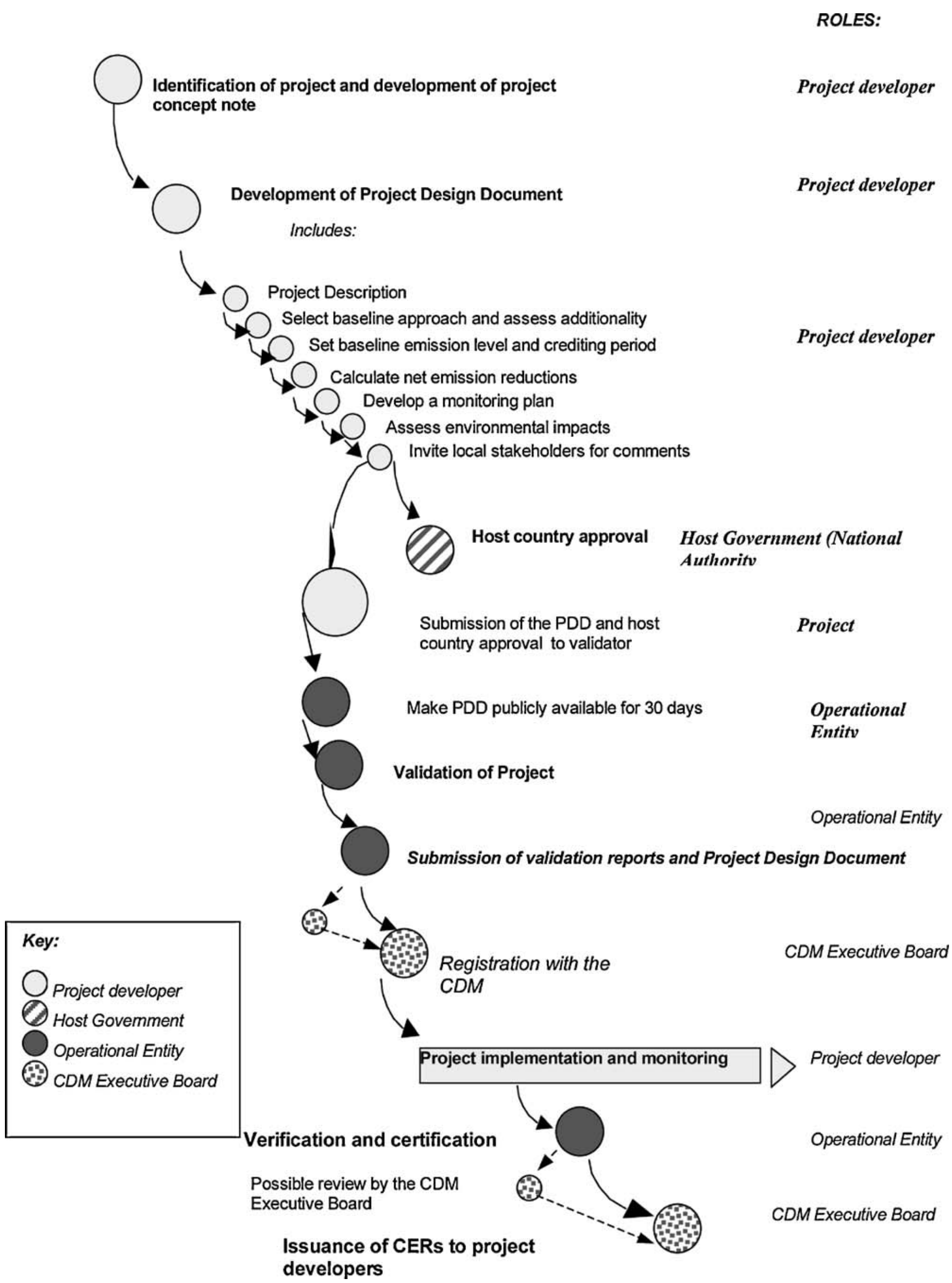


Fig. 2. A simplified CDM project flow diagram [12].

countries), agreed to legally binding reductions in greenhouse gas emissions of an average of 6–8% below 1990 levels between the years 2008–2012, defined as the first emissions budget period. The Kyoto Protocol set three mechanisms for the reduction in GHG emissions, i.e., emissions trading—known as "the carbon market"; the Clean Development Mechanism (CDM); and Joint Implementation (JI). Under CDM, developed Annex 1 parties may purchase ER units (ERUs) including certified ERs (CERs) from non-Annex 1 developing countries.

The key players involved in a CDM project are the:

- UNFCCC Executive Board (EB), responsible for setting the rules (methodologies), registration of project activities and approving the issuance of CERs;
- Designated National Authority (DNA), the body granted responsibility by a Party (signatory to the Kyoto agreement) to authorise and approve participation in CDM projects;
- Project Participant, a private and/or public entity authorised by a Party involved to participate in a CDM project activity; and
- Designated Operational Entity (DOE), independent auditors who are engaged by the Project Participant and assess whether a potential project meets all the eligibility requirements of the CDM (validation) and whether the project has achieved greenhouse gas ERs (Verification and Certification).

The rules for Clean Development Mechanism (CDM) projects to receive Certified Emission Reductions (CERs) are detailed and can be found in the CDM Rule Book [1] and the Users Guide [12]. There are 15 sectors for CDM projects of which 'Waste Handling and Disposal' is sector 13. The CDM process is well documented, as illustrated in Fig. 2. There are four types and scale of CDM project:

1. Large-scale project activities (CDM-LSC);
2. Small-scale project activities (CDM-SSC);
3. Afforestation and reforestation project activities (CDM-AR); and
4. Small-scale afforestation and reforestation project activities (CDM-SSC-AR).

Virtually all waste handling and disposal projects, including landfill gas combustion, fall into small-scale project activities (CDM-SSC). The first task in any waste handling and disposal CDM project is to plan and assess the viability of the project, and get support from the owner of the waste. Once the viability of the project has been assessed and a Project Idea Note (PIN) acknowledged by the UNFCCC, then the CDM project can be developed. There are essentially two phases to a CDM project, each with four stages as shown in Fig. 2: Phase One Registration of the project by the UNFCCC (1. Project Design Document (PDD); 2. Letters of Approval; 3. Validation; 4. Registration); and Phase 2 issuance of Certified ERs (CERs) (5. Monitoring; 6. Verification; 7. Issuance; 8. Forwarding), i.e.

1. *Project Design Document (PDD).* This is a key CDM document that details the project and all other CDM documents associated with it. The content required for a PDD is set out in full in UNFCCC 4/CMP1, Annex II, Appendix B, paragraph 2 [17] and the template for a CDM-SSC PDD can be found at http://cdm.unfccc.int/Reference/PDDs_Forms/PDDs/index.html. A PDD must describe the baseline methodology; establish the duration and crediting period of the project (either 10 years or 7 years twice renewable (21 years)); demonstrate how the project is additional; describe the environmental impacts of the project and provide a Record of Decision (RoD) regulatory authorisation based on an Environment Impact Assessment (EIA)); provide information on the sources of public funding for the project; summarise stakeholder comments (notably from the RoD process); describe the Monitoring Plan (for the monitoring of the project and ERs); and set out all relevant calculations. The PDD is one of the three documents required for a CDM project to be registered, along with the Validation Report from the Designated Operational Entity (DOE) and the Letter of Approval from the Designated National Authority (DNA).
2. *Letter of Approval.* From the DNA and submitted by the DOE.
3. *Validation.* The project needs to be constructed for Validation. The DOE then inspects the construction, operation and monitoring of the project of compliance with the PDD and any supporting documentation.
4. *Registration.* The DOE applies for Registration in the form of a Validation Report to the UNFCCC Executive Board (EB). Once projects are registered they are eligible to claim CERs from the UNFCCC EB to sell on the world market.
5. *Monitoring.* All greenhouse gas (GHG) ERs from the project must be monitored in accordance with the Monitoring Plan.
6. *Verification.* The DOE will confirm the authenticity of reductions in greenhouse gas emissions by a CDM project over a defined period of time, e.g., a year, and lodge a Certification Report with the UNFCCC EB.
7. *Issuance.* On acceptance of the Certification Report, the UNFCCC EB will issue CERs. The UNFCCC retains an Adaptation Share of Proceeds to cover its costs and fund measures in developing countries to assist them in adapting to the adverse effects of climate change.
8. *Forwarding.* This is the process of forwarding CERs to the Project Participants.

There are also fundamental rules for the application of CDM projects. To Register under the CDM a project must be able to demonstrate "Additionality", i.e., that the project will not be viable and will not proceed without the sale of ER credits. The rules for "Additionality" are given UNFCCC EB 39 report annex 10 [19]. Projects, which could be implemented without CER income, do not show "Additionality" and do not qualify for CERs. Also, if there is legislation in the country, which requires landfill gas to be extracted, and combusted, then the project does not demonstrate "Additionality" and cannot qualify for CDM funding. The eThekwini projects would not have gone ahead without CER income. This "Additionality" is clearly demonstrated in the viability assessment made below.

4.2. PDD, Validation and Registration

A single PDD was initially prepared for the three sites in July 2004. This was subsequently split into separate PDDs for Components One and Two, which were finalised and submitted to the UNFCCC for project Validation and Registration after RODs were received for the sites. Both PDDs were based on approved baseline methodology AM0010 "Landfill gas capture and electricity generation projects where landfill gas capture is not mandated by law" which had been prepared on the basis of the proposals for the three eThekwini sites [15].

The PDDs in compliance with AM0010 include a Primary method for the calculation of CERs and a secondary Quality Assurance method, which is used as backup and for quality control purposes. The two methods are illustrated in Figs. 3 and 4. The Primary method is based on downstream metering of the electricity generated, and includes all of the conservative factors assumed for the heat rate of the engines, the engine methane combustion efficiency, and transformer losses. The Quality Assurance method relies on upstream metering and continuous analysis of the methane content of landfill gas combusted and is considered by the authors as a more accurate calculation of the

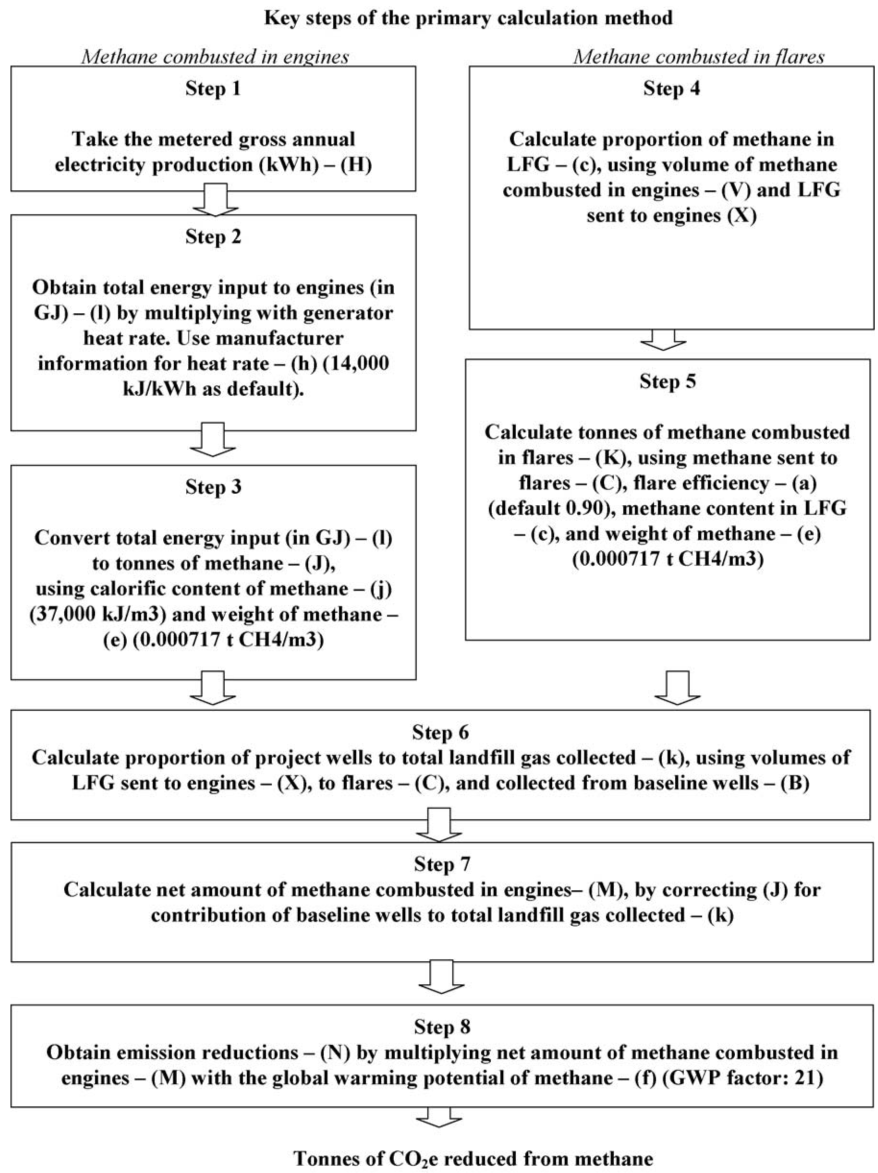


Fig. 3. PDD Primary Method, Component Two.

ERs. It should be noted that ERs from the displaced grid electricity (which would have been generated by Eskom from fossil fuels) are added to the ERs calculated through the Primary method. This is based upon the published Eskom grid emission factor (http://www.eskom.co.za/live/index.php), which is updated annually.

The Primary method as shown in Fig. 3 uses the monthly aggregates of the following four metered variables: Gross electricity production (kWh), volume of LFG sent to engines, volume of landfill gas flared and volume of LFG extracted from baseline wells (all in m^3). The method first calculates the quantity of methane combusted in engines using engine kWh output and technical parameters (Steps 1–3 in Fig. 3). Step 4 calculates the methane content in LFG using the quantity of LFG sent to engines, which is then used in Step 5 to derive methane combusted in flares from LFG quantity sent to flares. Step 6 calculates the proportion of LFG collected from project wells using the above information about LFG sent to engines as well as LFG collected from baseline wells. This proportion is used in Step 7 to calculate the net amount of methane combusted by the project activity for electricity generation and for which credits can be claimed. Step 8 concludes the calculation in multiplying by the global warming potential of methane. The Primary method is conservative and under-calculates the actual ERs.

The Quality Assurance method uses the monthly aggregates of the following three metered variables: Volume of landfill gas flared, volume of gas extracted from baseline wells, and volume of gas extracted from project wells (all in m^3). The method also uses continuous analysis of the methane content in landfill gas (Step 1), and first calculates the proportion of LFG combusted using the above gas flow information together with the flare efficiency (Step 2). In Step 3, this proportion is used to derive the volume of combusted gas that is collected from project wells. Step 4 calculates the volume of methane combusted from the volume of combusted gas using continuous measurement of the methane content in LFG. Steps 5 and 6 complete the calculation of ERs (in tCO_{2e}) by converting methane volume into tons of methane and multiplying by the global warming potential.

The main CDM issue for eThekwini Municipality with Component Two has been the interpretation of UNFCCC Methodology AM0010 under which this project was registered. The Durban projects were one of the first UNFCCC CDM landfill gas ER projects. When it was initiated there was no UNFCCC methodology for landfill

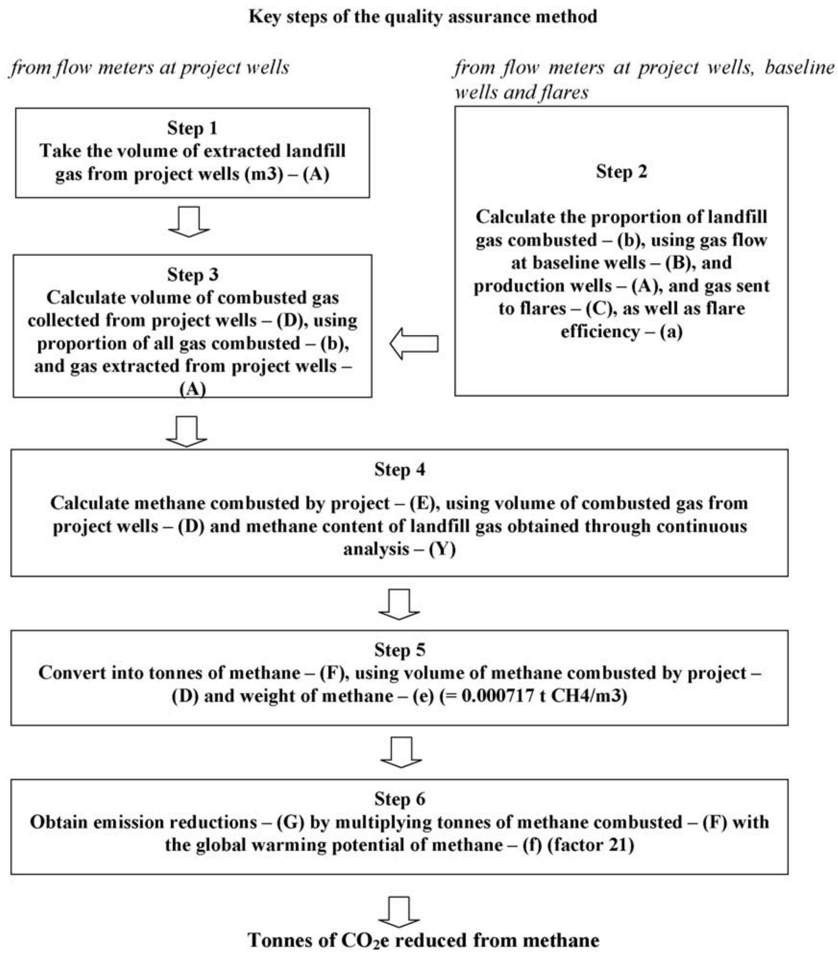


Fig. 4. PDD Quality Assurance, Method Component Two.

gas projects, and the eThekwini CDM team worked with the World Bank PCF and UNFCCC in the development of AM0010: Approved baseline methodology 'Landfill gas capture and electricity generation projects where landfill gas capture is not mandated by law' July 2004 [15]. This was quickly replaced by ACM0001: Approved consolidated baseline methodology 'Consolidated baseline methodology for landfill gas project activities' September 2004 [16].

The eThekwini projects were based and costed on the principle that all ERs from the combustion of landfill gas in flares and engines, and from the offset of emissions from the combustion of fossil fuel would be accepted [11]. TÜV SÜD, the World Bank Validator for both Components validated the project based on the PDD and AM0010 to include ERs for gas combusted in a flare. The principle for the operation of the eThekwini landfill gas combustion projects is that gas should be combusted in an engine, but all balancing gas, and surplus gas when the engines are inoperative due to maintenance, should be combusted in a flare. TÜV SÜD stated that AM0010 does not specifically reference landfill gas combusted in a flare, rather it relates to landfill gas capture and electricity generation projects. The Component Two PDD was submitted for registration in June 2008, but TÜV SÜD could not validate it as they believed the UNFCCC would not register the project, because the PDD included for ERs from gas flaring, and AM0010 does not specifically reference gas flaring. Despite arguments that Component One had been registered against AM0010 with gas flaring, and that AM0010 was drafted from the eThekwini projects on the basis of including gas flaring and emissions are clearly being reduced by the flaring activity, TÜV SÜD advised that that they would only validate the PDD if CERs from flaring were omitted from the PDD. The PDD still discussed flaring, but gas combusted in the flare was omitted from the CER calculations. To expedite the process, eThekwini accepted TÜV SÜD's advice for Registration with the intention to appeal the gas flaring issue with the UNFCCC Executive Board (EB). On this basis, the Component Two PDD was registered in March 2009.

The first verification for CERs to the end of August 2009 for Component Two was sought in October 2009. DNV was appointed as the DOE. The flaring question was raised with DNV and whilst they acknowledged that the flare was making ERs, they stated the PDD did not include for CERs from gas flaring. The eThekwini team has therefore raised the matter with the Secretariat of the UNFCCC, to seek a ruling on the interpretation of AM0010 to include gas combusted in a flare. If the Secretariat rules that ERs from flare combustion should not be counted as CERs under AM0010, eThekwini will either seek lower value credits under the Voluntary Carbon Standard (VCS), or seek to have the projects re-registered under ACM0001 which allows for CERs from gas flaring.

Component One was validated by TÜV SÜD and registered by the UNFCCC on 15th December 2006 as Project 0545 http://cdm.unfccc.int/Projects/DB/TUEV-SUED1154520464.04. This was the first waste CDM project to be registered in Africa. Component Two was also validated by TÜV SÜD and registered on 26th March 2009 as Project 1921 http://cdm.unfccc.int/Projects/DB/TUEV-SUED1214927681.45/view. The bulk of the time taken in achieving Registration was in gaining approval from the Validator, TÜV SÜD. A summary of the CERs predicted in the PDDs for Components One

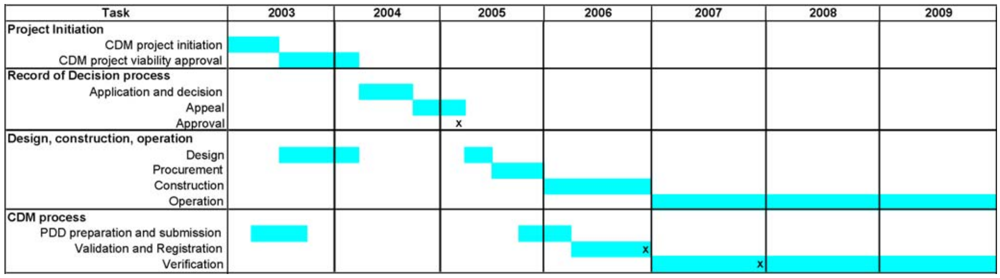


Fig. 5. Component One timeline.

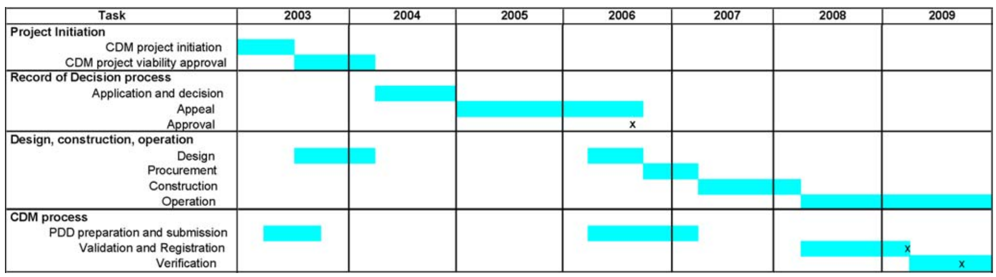


Fig. 6. Component Two timeline.

Table 4
PDD predicted and actual CERs for 2009.

Sites	Design for CERs			Actual for CERs		
	Gas extracted (m^3/h)	Electricity (MW)	CERs (year)	Gas extracted (m^3/h)	Electricity (MW)	CERs (year)
Mariannhill landfill	436	0.5	32,478	350	0.6	16,000
Bisasar Road landfill	3741	5	268,582	4000	6.5	218,000

and Two for 2009 is given in Table 4. A summary of the programmes for Components One and Two are shown in Figs. 5 and 6.

4.3. Verification and Issuance

The World Bank PCF appointed JCI of Japan as the Designated Operational Entity (DOE) to Verify ERs for Component One from 15th December 2006 to 1st November 2007. JCI visited Durban in January 2007 to commence the verification process, during which one Corrective Action Request (CAR) and three Forward Action Requests (FARs) were raised.

JCI visited Durban again in January 2008 for the first verification period to 1st November 2007. The main technical issue arose from the verification was that JCI would not verify emissions destroyed in the flares at 97% destruction, although eThekwini had manufacturers' test certificates which demonstrated at least 98.8% efficiency (upper accuracy limit of the monitoring equipment) at above 750°C. The validators applied the UNFCCC Annex 13 Methodology from Executive Board 28 [18], which states the default methane destruction value for enclosed flares is 90% at above 500 °C. For higher efficiencies to be claimed, there needs to be continuous monitoring of the methane destruction efficiency of the flare (flare efficiency), and the equipment specified and supplied for the project was not designed to do this.

24,322 CERs were claimed for this period. Ten CARs and two FARs were issued which primarily related to generator efficiency, generator heat rate tests, equipment failure and quality management. A further 2785 VCS (Voluntary Carbon Standard) VERs (Verified ERs) were also claimed from commencement of operations in November 2006 to Registration on 15th December 2006. Over 50,000 ERs were destroyed on the Component One project since 1st November 2007 through to December 2009. The second verification period for Component One was from 2nd of November 2007 to 28th of February 2010. 46,865 CERs have been claimed for this period with DNV (Det Norske Veritas) as the DOE. Fortunately, eThekwini's ERPA with the PCF is not dependent on the issuance of CERs by the UNFCCC EB, only upon the recording of ERs. eThekwini therefore has received two payments to date from the PCF for ERs from Component One.

DNV was appointed as the DOE also for Component Two. To generate some cash flow, Verification of VERs was sought from March 2008 to the end of August 2009, and CERs from March 2009 to the end of August 2009. Monitoring Reports for VERs and CERs were issued to DNV in September 2009. DNV visited Durban in November 2009 and issued draft Verification Reports for CERs and VERs at the end of January 2010 with seven CARs, seven CLs (clarification requests) and no FARs. These CARs and CLs related to generator efficiency, generator heat rate tests and equipment failure. The ongoing process for issuance of CERs involves the Project Participants responding to the Corrective Action and Clarification requests from the DOE, and then the DOE may take 1–2 months to issue the Final Verification Report. The Final Verification Report will then be sent to the UNFCCC and a request for issuance of CERs will be submitted. The UNFCCC then performs a completeness check of the Final Verification Report, which usually takes 1 to 2 months. If the documentation is found to be complete, it will be followed by a publication period of 15 days. During this publication period, EB members and Kyoto Parties (countries) can raise requests for review. If no such requests are raised, then the report is automatically accepted. However, if three members of the Executive Board of the UNFCCC (EB) raise a request

for review or request for minor corrections, these requests are sent to the DOE and the Project Proponent with a 2-week deadline to respond. The response is considered at the next EB meeting (usually it is 4–6 weeks between EB meetings). If the EB accepts the response, the report is accepted. If not, it goes through another review, until the next EB meeting. Experience shows that the best-case scenario is about 8 to 10 weeks from submission of request for issuance to notification of issuance in the CER account. For the eThekwini project, CERs are expected to be issued around July 2010, over 10 months after the initial request for Certification and Issuance.

5. Project delivery

5.1. Procurement and construction

Component One and Two were procured separately with a gas extraction and flaring contract, and generator contract for each (four contracts in all, WS5607 and WS5608 for Mariannhill and La Mercy; and WS5627 and WS5628 for Bisasar Road). Jenbacher 312 (0.5 MW) and 320 (1 MW) type engines were found the most competitive and attractive as they are based on gas engine design and offer a greater range in their output from around 50% to full load (e.g., 0.5–1 MW). This meant that rather than two 0.5 MW engines for Mariannhill, a single 1 MW engine could be specified. Also, based upon gas being extracted from wells constructed at Bisasar Road in 2005, it was decided to procure four 1 MW engines.

The two Component One contracts were procured in the autumn and winter of 2005. The contract costs for Component One WS5607 extraction and WS5608 generator contracts were $1 m and $1.1 m, respectively. The works were commenced in January 2006 with a six-month construction and 2-month delivery period for the generators. The first gas was combusted from the new contracted works and VERs generated from November 2006. The works were completed and the generators were installed and commissioned by December 2006, whereas the CDM project was validated in January 2007.

The Component Two contracts were procured in January 2007; the extraction works cost and the 4 MW generator contract cost $3.1 m each. The works were constructed and operational by March 2008. A further two 1 MW generators were designed, procured, installed and commissioned by July 2009.

6. Factors affecting the viability of the project

6.1. The verification process

The Component One PDD predicted an average CERs of 68,833 tCO_{2e} per year over the first 7 years, and the Component Two PDD predicted an average of 342,705 tCO_{2e} per year over the first 7 years. The models for Mariannhill and Bisasar Road had CERs of 32,476 and 269,582 tCO_{2e} for 2009, whereas the actual CERs are some 16,000 and 218,000 tCO_{2e}, respectively. That is some 50% and 80% of the CERs predicted.

The gas management systems have provided less ERs than originally calculated due to:

- Power outages causing engine failure. An operative then has to be sent out to restart the engines, as the sites are not manned out of normal landfill operating hours. Power outages also causes concern as repeated failure and restart causes wear to the engines;
- Initial failure of an engine due to poor maintenance at the Mariannhill landfill in 2008;
- The La Mercy site being removed from the CDM project. Less gas than modelled is generated at the site. Knowledge has been gained since 2003, which shows the waste, has a lower biodegradable content than assumed, and the gas profile fluctuate. The high leachate water-levels also prevent an easy biogas extraction;
- The Verifiers could only certify 90% reduction in flares due to the UNFCCC EB report from 2006, whereas 97% had been initially assumed. The UNFCCC monitoring methodology EB report Annex 13 for the combustion of methane gas in an enclosed flare has a default value of 90% [18] where the flare is operating within the manufacturer's specification. This can be increased to the actual combustion within the flare where the methane destruction is recorded by monitoring the flare emissions. This is a conservative factor of 10% of the gas combusted in the flares;
- Conservative values are used for Verification for parameters that are not continuously measured or are uncertain. For example; a conservative value for the engine heat rate factor is taken as a new engine but this increases with age; a conservative value are taken for the combustion efficiency the engines (it was assumed the engines would have 100% methane combustion efficiency, whereas only 97.5% is guaranteed); a conservative figure has been taken for the calorific value for methane; electricity is metered downstream of transformers and conservative values are taken for transformer losses;
- The PDD takes a low calorific value of landfill gas of 37,000 kJ/m^3 for calculations for engines. This overestimates the engines' efficiency and less gas is combusted/energy used in the calculation of CERs. For methane supplied in gas pipelines, the calorific value is 37,500–43,000 kJ/m^3 [5], and the calorific value for methane in landfill gas methane is taken as 38,600 kJ/m^3 [4];
- The Eskom conservative grid emission factor is used, and grid emissions in the Republic of South Africa are higher than this;
- The Validators for Components One and Two, TÜV SÜD, included flaring in Component One and excluded it in Component Two. Flaring typically represents 20% of the ERs for Component Two. This constitutes the difference between the 218,000 tCO_{2e} achieved and the 269,582 tCO_{2e} predicted for 2009 for Component Two.

In addition to all of the conservatism in the calculation and verification of CERs detailed above, the UNFCCC has adopted a conservative value of the global warming potential (GWP) of methane (CH_4) against carbon dioxide (CO_2). The UNFCCC uses the revised 1996 IPCC Guideline for National Greenhouse Gas Inventories value of 21 times, whereas it is scientifically proven that it is between 21 times and 27 times [2]. eThekwini tried, unsuccessfully, in 2003 to persuade the UNFCCC to adopt a value of 23 in the development of AM0010. This resulted in a further 9% reduction in the actual ERs of the project, for a total loss of some 20%. This figure does not include the under issuance of CERs for not including flaring in Component Two.

The current gas recovery rate at the Mariannhill landfill is around 350 Nm^3/h and it is around 4000 Nm^3/h at Bisasar Road. To date, there have been 58 vertical wells, 36 upslope liner risers and 19 horizontal wells constructed at Bisasar Road. The most productive wells are horizontal wells laid in the fresh waste. One horizontal well around 150 m long is yielding over 300 m^3/h. The next most productive wells are the upslope risers, with the traditional vertical wells not yielding as much gas as these.

The Jenbacher landfill gas fuelled generators (engines) have performed well. There was an initial problem with 1 MW engine at the Mariannhill site due to de-coking and oil management. However, lessons were learnt from this. The system was modelled with each engine operating 8000 h a year (91% efficiency), with the remaining time down for maintenance. For the last 6 months of 2009, the Bisasar Road engines operated at over 91% efficiency, recording an efficiency of 96% in January 2010. Overall, the 1 MW engine at Mariannhill operates around 60% load (600 kW). The

CERs are 15,000–20,000 tCO_{2e} per year, with some 3750–4250 MWh per year.

6.2. Renewable Energy Feed-In Tariff (REFIT)

In 2004 the financial model for the project used the eThekwini Electricity tariff for the purchase of electricity at 0.017$ kWh. The tariff paid by eThekwini Electricity varies during the day depending on electricity demand. This tariff has increased with inflation and the average payment in 2007 for electricity generated on the Component One project was 0.019 $ kWh. The tariff for the sale of electricity to consumers is higher than the price paid to producers to cover eThekwini Electricity transfer and management costs. The average standard demand tariff is 0.036$ kWh but on 1st July 2009 this was increased to 0.047$ kWh to include an environmental levy [9].

South Africa is a signatory to the Kyoto Protocol and is seeking to implement laws to reduce its GHG emissions. The Government considers that South Africa has good potential for green energy and is striving to achieve the target of 10,000 GWh from renewable sources by 2013 [6]. To contribute towards this target and towards socio-economic and environmentally sustainable growth, and kick start and stimulate the renewable energy industry in South Africa, on 26th March 2009 (the same day that Component Two was Registered), the Government passed into law the Renewable Energy Feed-In Tariff (REFIT) mechanism to promote the deployment of renewable energy [6]. This places an obligation on specific entities to purchase the output from qualifying renewable energy generators at pre-determined premium prices, where renewable energy is defined as naturally occurring non depletable sources of energy, such as solar, wind, biomass (including landfill gas), hydro, tidal, wave, ocean current and geothermal. These sources of energy can produce electricity, gaseous and liquid fuels, heat or a combination of these energy types. Feed-in Tariffs (FIT) is, in essence, guaranteed prices for electricity supply rather than conventional consumer tariffs. The basic economic principle underpinning the FIT is the establishment of a tariff (price) that covers the cost of generation plus a "reasonable profit" to induce developers to invest in green energy. This approach has been adopted in many other countries around the world [10,8]. Under this approach it becomes economically appropriate to award different tariffs for different technologies. The four technologies that REFIT is focusing upon are landfill gas ($0.129 kWh), small hydro ($0.134 kWh), wind ($0.179 kWh) and Concentrating Solar Power (CSP) ($0.30/kWh). REFIT should provide increased energy security; resource saving; exploitation of South Africa's significant renewable energy resource; pollution reduction; climate friendly development; employment creation; acceptability of society; support to a new industry sector; and protecting natural foundations of life for future generations. The term of the REFIT Power Purchase Agreement is 20 years.

It is questionable whether REFIT will apply to electricity generated by landfill gas CDM projects, as current guidelines state that carbon revenue from the CDM shall be excluded from REFIT [7]. It is, however, considered that REFIT should apply to existing and new CDM projects in South Africa, provided it can be demonstrated that the CDM project would not go ahead without REFIT. It is considered that REFIT should apply to the eThekwini Component One project, but unfortunately there is no clarity on REFIT practical implementation and associated timeframes, as this scheme is still in its developmental phase.

6.3. Viability

Income for eThekwini project is received from CERs and VERs for the combustion of methane in the landfill gas generators, for methane combusted in the flare for Component One, for avoided emissions, and from the sale of electricity. However, all of the factors listed above in 6.1 have conspired to reduce the actual income.

Both components have been modelled to assess their viability at the end of 2009. A weighted average cost of 10% has been assumed for capital. The model includes $2.5 capital investment through the Department of Trade and Industry Critical Infrastructure Programme. For the Mariannhill site, the model shows:

(1) The site is likely to produce around 20,000 CERs tCO_{2e} per year ongoing to around 2023 when the site closes;
(2) CDM income will not pay back the cost for the project over the potential 21 year CDM period. In hindsight, the Component One gas to electricity project is not viable on its own at a CDM income of $3.95 tCO_{2e};
(3) If the engine had not been installed, the project would still not be viable at a CDM income of $3.95 tCO_{2e}, i.e., it is not viable as a flaring project at $3.95 tCO_{2e} per CER;
(4) The Mariannhill project (excluding La Mercy) is still not viable with an engine installed at a CDM income of over $14 tCO_{2e};
(5) Component One is viable with a payback period of 15 years by just flaring and a CDM income of over $14 tCO_{2e};
(6) If the Mariannhill site only had been constructed with a flare, it would have had a 7-year payback period at a CDM income of over $14 tCO_{2e};
(7) The project would beviable with a payback period of 19 years with a REFIT income of $0.129 kWh and a CDM income of $3.95 tCO_{2e};
(8) The Mariannhill site payback period would be only 5 years with a REFIT income of $0.129 kWh and a CDM income of over $14 tCO_{2e};
(9) Whilst the capital cost has not been repaid yet by the generated income, the operating costs have been met and, therefore, it is considered viable to continue operating the Mariannhill project; and
(10) When the Component One and Two are combined, they will have a combined payback period of only 6 years from 2007 to 2012, and consequently the overall CDM project would be financially justified.

The model analysis for the Bisasar Road site concludes:

1. The site is likely to produce around 250,000 CERs tCO_{2e} per year to around 2013 (expected closure time);
2. The payback period for the project is some 4 years from 2008 to 2011 with no CER income from flaring. There is no certainty of the income after the end of the Kyoto Protocol in 2012, but eThekwini has an agreement with the UNFCCC for 21 years, and income to the Municipality should be forthcoming after 2012;
3. The payback period in the 2004 financial model for the two components was 4 years at $3.95/CER. A recent analysis estimates that the payback period for the Bisasar Road Component Two alone can be 4 years only at over $14/CER;
4. CERs from the flare and REFIT income will provide payback earlier in 2011; and
5. The Component Two project would not have been viable at $3.95/CER.

The Bisasar Road landfill is planned to close in 2013 although eThekwini is seeking to maximise the life of the landfill, and the viability of the CDM project, by restricting inert waste disposal at the site. eThekwini Municipality has sufficient gas at present to power another 1 MW engine. The gas is currently being flared without CDM–CER income. The viability model has assessed the provision of a further 1 MW engine and concludes:

1. At over $14/CER the engine would have a 4-year payback period. If purchased in 2010, it would not be operational until 2011, and would not be paid off until 2015. If the site closes in 2013, the gas may deplete before 2015 and impacting on the long-term viability of the project;
2. The Municipality would generate more income if the Mariannhill engine was transferred to Bisasar Road and the gas at Mariannhill was flared.

7. Conclusions

Component One was always considered as an initial "learning exercise" for Component Two, and valuable lessons were learnt from the former that have made the latter a success.

Lessons learnt from the projects include:

1. The Municipality should assemble a team of experienced landfill gas experts to develop the project, with knowledge transfer to skill internal staff;
2. Gas pumping trials should be carried out first before the PDD to establish how much gas can be extracted from the landfill;
3. Gas generation patterns from African landfills tend to fluctuate due to climatic conditions and higher biogenic waste content than Annex 1 countries;
4. Medium sized CDM landfill gas utilisation projects are not viable in Africa unless there is a renewable energy tariff (REFIT).
5. Medium sized CDM projects should be viable in Africa with just the flaring of gas;
6. Engines supplied should be flexible to run on a varying load (e.g., 50–100%);
7. The CDM methodologies are very conservative and under-calculate CERs which may put marginal projects at risk; and
8. It takes up to a year for the issuance of CERs after conclusion of a combustion period, i.e., income from the first ERs may not be obtained for over 2 years.

The main issues for eThekwini Municipality in the implementation of the CDM projects have been time and cost, complexity of the CDM process, conservative and inflexible methodologies. These are all linked to the security of the CDM process to guarantee CERs and ensure that GHG emissions have been reduced by such projects. There have been no issuance of CERs to date for Components One and Two, but issuance is expected in 2010.

The Component One project shows that small to medium sized landfills accepting 500–1000 tpd MSW are not viable with gas utilisation unless there is a premium tariff for non-fossil fuel green electricity like REFIT. For large landfills such as Bisasar Road accepting up to 5000 tpd CDM projects are viable despite the 6-year period required to obtain a meaningful return on capital investment, i.e., 2 years for the design and construction; 3 years operation; and up to 1 year for issuance of CERs. This should be an acceptable timescale commitment for any investors and the Municipality. These schemes can be affected by externalities such as fluctuations in the quantity of gas generated with changing disposal rates and waste composition over a period of time, uncertainties in CER prices after the 2012 end date for the Kyoto Protocol, volatility in the VCS and VER prices.

The Copenhagen Conference of Parties (CoP15) failed to deliver a binding treaty to replace the Kyoto Protocol when it expires in 2012. It is predicted that investors' interest in CDM-approved ER projects may reduce without greater certainty over what will happen to the scheme post 2012. The CDM Executive Board maintains that interest in gaining CDM accreditation remains robust, with almost 2000 projects now registered and 4200 in the pipeline. However, analysts are increasingly concerned that investors will back away from the sector without greater certainty that they will be able to continue to sell certified ER credits at a good price post 2012. UNFCCC CoP 16 (Conference of Parties) in Mexico in November 2010 (http://unfccc.int/meetings/unfccc_calendar/items/2655.php) needs to address this and put in place a post 2012 CDM mechanism.

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References

[1] Baker, McKenzie. CDM rule book. Baker & McKenzie's global climate change practice; August 2008. http://www.cdmrulebook.org/Page/home.
[2] Boucher O, Friedlingstein P, Collins B, Shine KP. The indirect global warming potential and global temperature change potential due to methane oxidation; October 2009. http://www.iop.org/EJ/article/1748-9326/4/4/044007/erl9_4_044007.html.
[3] Gregory RG, Attenborough GM, Hall DH, Deed C. The validation and development of an integrated landfill gas risk assessment model: GasSim. In: Ninth international waste management and landfill symposium; October 2003.
[4] dti. Estimated average gross calorific values of fuels; 2010. http://www.apletonlemoors.co.uk/docs/calorific_values.PDF.
[5] National Grid. Calorific value description; 2010. http://www.nationalgrid.com/uk/Gas/Data/help/opdata/index.htm.
[6] NERSA. Renewable Energy Feed-in Tariff (REFIT) South Africa. National Energy Regulator of South Africa. Regulator Guidelines; 26 March 2009. http://www.nersa.org.za/UploadedFiles/ElectricityDocuments/REFIT%20Guidelines.pdf.
[7] NERSA. Renewable Energy Feed-in Tariff (REFIT) South Africa. National Energy Regulator of South Africa. Media Statement; 31 March 2009. http://www.nersa.org.za/documents/Press%20Release/Media%20Statement%20Announcement%20of%20REFIT%20decision%2031%20March%202009.pdf.
[8] OFGEM. Renewable obligation. Office of gas and electricity markets; February 2010. http://www.ofgem.gov.uk/Sustainability/Environment/RenewablObl/Pages/RenewablObl.aspx.
[9] Polity. Regulator grants Eskom 31.3% tariff increase. Policy, law, economics and politics; 20th February 2010. http://www.polity.org.za/article/regulator-grants-eskom-313-tariff-increase-2009-06-26.
[10] REA. Renewable electricity: the Non-Fossil Fuel Obligation (NFFO). Renewable Energy Association; February 2010. http://www.r-e-a.net/policy/renewables/electricity/NFFO.
[11] Strachan LJ, Pass J, Couth B. Trading landfill gas: kick-starting the green gas-to-energy. WasteCon 2006. In: Eighteenth waste management conference and exhibition; October 2006.
[12] UNDP. Chapter 2: going through the CDM process: a user's guide. United Nations Development Programme; 2010. http://www.undp.org/energy/docs/cdmchapter2.pdf.
[13] United Nations. Rio Earth Summit 1992: United Nations Convention on Climate Change. United Nations Conference in Environment and Development (UNCED); June 1992. http://unfccc.int/essential_background/convention/items/2627.php.
[14] United Nations. Kyoto Protocol 1997: United Nations Convention on Climate Change (UNFCCC). UNFCCC; 11 December 1997. http://unfccc.int/kyoto_protocol/items/2830.php.
[15] United Nations. AM0010: approved baseline methodology 'Landfill gas capture and electricity generation projects where landfill gas capture is not mandated by law'. UNFCCC; July 2004. http://cdm.unfccc.int/UserManagement/FileStorage/CDMWF_AM_675903718.
[16] United Nations. ACM001 approved consolidated baseline methodology 'Consolidated baseline methodology for landfill gas project activities'. UNFCCC; September 2004. http://cdm.unfccc.int/UserManagement/FileStorage/eb15repan1.pdf.
[17] United Nations. Report of the conference of the parties serving as the meeting to the Parties to the Kyoto Protocol, Montreal, December 2005. UNFCCC; 30 March 2006. http://cdm.unfccc.int/Reference/COPMOP/08a01.pdf#page=43.
[18] United Nations. EB 28 Annex 13 Methodological 'Tool to determine project emissions from the flaring of gases containing methane'. UNFCCC; December 2006. http://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-06-v1.pdf.
[19] United Nations. EB 39 Report Annex 10 Methodological Tool' 'Tool for the assessment and determination of additionality' (Version 05.2). UNFCCC; May 2008. http://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-01-v5.2.pdf.